

Mrs. Bryant, in the course of an address on "Ideals of Study" at the London School of Medicine for Women, said that an ideal of study was most usefully conceived, not as a scheme of learning to be achieved, but rather in its psychological essence as growing out of the primitive intellectual interests of human beings. Interest in knowledge for its own sake—the theoretic interest—was to be found more or less in every healthy normal person. According to brain type, habit, association, and other circumstances, its bent towards one or another branch of knowledge varied in individuals.

It was suggested that more should be done in elementary and secondary education (1) to develop the practical interest in relation to all the every-day problems arising naturally in the environment; and (2) to train it to a high ideal of the science and skill involved in their solution. The neglect of the practical interest in the practically minded was not only loss of good material for practical efficiency; it was also the loss of opportunity for the cultivation of the scientific interest. To inquire how a thing was made led to inquiry as to its causation, and at that point the youth or child becomes athirst for science.

At the London School of Tropical Medicine, Dr. George Nuttall, F.R.S., delivered an address on "Scientific Research in Medicine," in the course of which he pointed out the great benefits to mankind which have followed such discoveries as those of the causes and prevention of yellow fever and malaria, and that the majority of such discoveries have been made by those engaged in research and in the realms of pure science, and rarely by those guided by principles of direct and immediate utility. He urged the necessity for the endowment of research, particularly in experimental medicine, and finally proceeded to review recent work in protozoology and parasitology.

At the School of Pharmacy, Pharmaceutical Society of Great Britain, Sir Boverton Redwood delivered the address on "General Study and Specialism," and at the Royal Veterinary College Mr. Hunting discussed the career of members of the veterinary profession.

### DIAMONDS.<sup>1</sup>

FROM the earliest times the diamond has fascinated mankind. It has been a perennial puzzle—one of the "riddles of the painful earth." It is recorded in "Sprat's History of the Royal Society" (1667) that among the questions sent by order of the society to Sir Philiberto Vernatti, resident in Batavia, was one inquiring "Whether Diamonds grow again after three or four years in the same places where they have been digged out?" The answer sent back was "Never, Or at least as the memory of man can attain to."

Of late years the subject has fascinated many men of science. The development of electricity, with the introduction of the electric furnace, has facilitated research, and I am justified in saying that if the diamond problem is not actually solved, there is every probability it shortly will be solved.

South Africa, as I will show in detail, is the favourite haunt of diamonds on this planet: it ranks with Australia and California as one of the three great gold-yielding regions. But the wealth of South Africa is not limited to gold and diamonds. It is also the illimitable home of coal—"the black diamond" of the universe. The province of Natal alone contains more coal than Britain ever owned before a single bucket had been raised; and the coal beds extend into the Orange River Colony. Valuable iron ores exist also in large quantities.

#### *The Pipes at Kimberley.*

The five diamond mines are all contained in a precious circle  $3\frac{1}{2}$  miles in diameter. They are irregular shaped round or oval pipes, extending vertically downwards to unknown depths, retaining about the same diameter throughout. They are considered to be volcanic necks, filled from below with a heterogeneous mixture of fragments of surrounding rocks, and of older rocks such as granite, mingled and cemented with a bluish coloured hard

clayey mass, in which famous blue clay the imbedded diamonds are hidden.

How the great pipes were originally formed is hard to say. They were certainly not burst through in the ordinary manner of volcanic eruption, since the surrounding and enclosing walls show no signs of igneous action, and are not shattered or broken up even when touching the "blue ground." It is pretty certain these pipes were filled from below after they were pierced, and the diamonds were formed at some previous time and mixed with a mud volcano, together with all kinds of debris eroded from the rocks through which it erupted, forming a geological "plum pudding." The direction of flow is seen in the upturned edges of some of the strata of shale in the walls, although I was unable to see any upturning in most parts of the walls of the De Beers mine at great depths.

The breccia filling the mines, usually called "blue ground," is a collection of fragments of shale, and of various eruptive rocks, boulders, and crystals of many kinds of minerals. Indeed, a more wildly heterogeneous mixture can hardly be found anywhere else on this globe. The Kimberley mines for the first 70 feet or 80 feet are filled with so-called "yellow ground," and below that with "blue ground." This superposed yellow on blue is common to all the mines. The blue is the aboriginal ground, and owes its colour chiefly to the presence of lower oxides of iron. When atmospheric influences have access to the iron it becomes peroxidised, and the ground assumes a yellow colour. The thickness of yellow earth in the mines is therefore a measure of the depth of penetration of air and moisture. The colour does not affect the yield of diamonds. The ground mass is soapy to the touch, and friable, especially after exposure to weather. Besides diamonds, more than eighty species of minerals have been recognised in the blue ground, the most common being magnetite, ilmenite, garnet, bright green ferriiferous enstatite (bronzite), a hornblende mineral closely resembling smaragdite, calc-spar, vermiculite, diallage, jeffreysite, mica, kyanite, augite, peridot, iron pyrites, wollastonite, vaalite, zircon, chrome iron, rutile, corundum, apatite, olivine, sahlite, chromite, pseudobrookite, perovskite, biotite, and quartz.

The blue ground does not show any signs of igneous action; the fragments in the breccia are not fused at the edges. The eruptive force was probably steam or water-gas, acting under great pressure but at no high temperature.

There are many such pipes in the immediate neighbourhood of Kimberley. It may be that each volcanic pipe is the vent for its own special laboratory—a laboratory buried at vastly greater depths than we have yet reached—where the temperature is comparable with that of the electric furnace, where the pressure is fiercer than in our puny laboratories and the melting point higher, where no oxygen is present, and where masses of liquid carbon have taken centuries, perhaps thousands of years, to cool to the solidifying point. The chemist arduously manufactures infinitesimal diamonds, valueless as ornamental gems; but nature, with unlimited temperature, inconceivable pressure, and gigantic material, to say nothing of measureless time and appalling energy, produces without stint the dazzling, radiant, beautiful, coveted crystals I am enabled to show you to-night.

This hypothesis of the origin of diamonds is in many ways corroborated.

The ash left after burning a diamond invariably contains iron as its chief constituent; and the most common colours of diamonds, when not perfectly pellucid, show various shades of brown and yellow, from the palest "off colour" to almost black. They are also green, blue, pink, yellow, and orange. These variations give support to the theory advanced by Moissan that the diamond has separated from molten iron—a theory of which I shall say more presently—and also explain how it happens that stones from different mines, and even from different parts of the same mine, differ from each other. Further confirmation is given by the fact that the country round Kimberley is remarkable for its ferruginous character, and iron-saturated soil is popularly regarded as one of the indications of the near presence of diamonds. Along with carbon, molten iron dissolves other bodies which possess

<sup>1</sup> Abridged from a lecture delivered before the British Association at Kimberley on September 5 by Sir William Crookes, F.R.S.

tinctorial powers. One batch of iron might contain an impurity colouring the stones blue, another lot would tend towards the formation of pink stones, another of green, and so on. Cobalt, nickel, chromium, and manganese, all metals present in the blue ground, would produce these colours.

An hypothesis, however, is of little value if it only elucidates half a problem. Let us see how far we can follow out the ferric hypothesis to explain the volcanic pipes. In the first place we must remember these so-called volcanic vents are admittedly not filled with the eruptive rocks, scoriaceous fragments, &c., constituting the ordinary contents of volcanic ducts.

Selections of thin sections of some of these rocks and minerals, mounted as microscopic objects and viewed by polarised light, are not only of interest to the geologist, but are objects of great beauty.

The appearance of shale and fragments of other rocks testifies that the mélange has suffered no great heat in its present condition, and that it has been erupted from great depths by the agency of water vapour or some similar gas. How is this to be explained?

You will recollect I start with the reasonable supposition that at a sufficient depth<sup>1</sup> there were masses of molten iron at great pressure and high temperature, holding carbon in solution, ready to crystallise out on cooling. Far back in time the cooling from above caused cracks in superjacent strata through which water<sup>2</sup> found its way. On reaching the incandescent iron, the water would be converted into gas, and this gas would rapidly disintegrate and erode the channels through which it passed, grooving a passage more and more vertical in the necessity to find the quickest vent to the surface. But steam in the presence of molten or even red-hot iron liberates large volumes of hydrogen gas, together with less quantities of hydrocarbons<sup>3</sup> of all kinds—liquid, gaseous, and solid. Erosion commenced by steam would be continued by the other gases; it would be easy for pipes, large as any found in South Africa, to be scored out in this manner.

Sir Andrew Noble has shown that when the screw stopper of his steel cylinders in which gunpowder explodes under pressure is not absolutely perfect, gas escapes with a rush so overpowering as to score a wide channel in the metal. Some of these stoppers and vents are on the table. To illustrate my argument Sir Andrew Noble has been kind enough to try a special experiment. Through a cylinder of granite is drilled a hole 0.2 inch diameter, the size of a small vent. This is made the stopper of an explosion chamber, in which a quantity of cordite is fired, the gases escaping through the granite vent. The pressure is about 1500 atmospheres, and the whole time of escape is less than half a second. Notice the erosion produced by the escaping gases and by the heat of friction; these forces have scored out a channel more than half an inch diameter and melted the granite along their course. If steel and granite are thus vulnerable at comparatively moderate gaseous pressure, it is easy to imagine the destructive upburst of hydrogen and water-gas grooving for itself a channel in the diabase and quartzite, tearing fragments from resisting rocks, covering the country with débris, and finally, at the subsidence of the great rush, filling the self-made pipe with a water-borne magma in which rocks, minerals, iron oxide, shale, petroleum, and diamonds are violently churned in a veritable witch's cauldron! As the heat abated the water vapour would gradually give place to hot water, which forced through the magma would change some of the mineral fragments into the existing forms of to-day.

Each outbreak would form a dome-shaped hill; the eroding agency of water and ice would plane these eminences until all traces of the original pipes were lost.

Actions such as I have described need not have taken place simultaneously. As there must have been many

molten masses of iron with variable contents of carbon, different kinds of colouring matter, solidifying with varying degrees of rapidity, and coming in contact with water at intervals throughout long periods of geological time—so must there have been many outbursts and upheavals, giving rise to pipes containing diamonds. And these diamonds, by sparseness of distribution, crystalline character, difference of tint, purity of colour, varying hardness, brittleness, and state of tension, have the story of their origin impressed upon them, engraved by natural forces—a story which future generations of scientific men may be able to interpret with greater precision than is possible to-day.

#### *Genesis of the Diamond.*

Speculations as to the probable origin of the diamond have been greatly forwarded by patient research, and particularly by improved means of obtaining high temperatures, an advance we owe principally to the researches of Prof. Moissan.

Until recent years carbon was considered absolutely non-volatile and infusible; but the enormous temperatures at the disposal of experimentalists—by the introduction of electricity—show that, instead of breaking rules, carbon obeys the same laws that govern other bodies. It volatilises at the ordinary pressure at a temperature of about 3600° C., and passes from the solid to the gaseous state without liquefying. It has been found that other bodies, such as arsenic, which volatilise without liquefying at the ordinary pressure, will easily liquefy if pressure is added to temperature. It naturally follows that if along with the requisite temperature sufficient pressure is applied, liquefaction of carbon will take place, when on cooling it will crystallise. But carbon at high temperatures is a most energetic chemical agent, and if it can get hold of oxygen from the atmosphere or any compound containing it, it will oxidise and fly off in the form of carbonic acid. Heat and pressure, therefore, are of no avail unless the carbon can be kept inert.

It has long been known that iron when melted dissolves carbon, and on cooling liberates it in the form of graphite. Moissan discovered that several other metals, especially silver, have similar properties; but iron is the best solvent for carbon. The quantity of carbon entering into solution increases with the temperature.

For the manufacture of—I am afraid I must say an infinitesimal—diamond, the first necessity is to select pure iron—free from sulphur, silicon, phosphorus, &c.—and to pack it in a carbon crucible with pure charcoal from sugar. The crucible is then put into the body of the electric furnace, and a powerful arc formed close above it between carbon poles, utilising a current of 700 amperes at 40 volts pressure. The iron rapidly melts and saturates itself with carbon. After a few minutes' heating to a temperature above 4000° C.—a temperature at which the iron melts like wax and volatilises in clouds—the current is stopped, and the dazzling fiery crucible is plunged beneath the surface of cold water, where it is held until it sinks below a red heat. As is well known, iron increases in volume at the moment of passing from the liquid to the solid state. The sudden cooling solidifies the outer layer of iron and holds the inner molten mass in a tight grip. The expansion of the inner liquid on solidifying produces an enormous pressure, and under the stress of this pressure the dissolved carbon separates out in transparent forms—minutely microscopic, it is true—all the same veritable diamonds, with crystalline form and appearance, colour, hardness, and action on light the same as the natural gem.

Now commences the tedious part of the process. The metallic ingot is attacked with hot nitro-hydrochloric acid until no more iron is dissolved. The bulky residue consists chiefly of graphite, together with translucent chestnut-coloured flakes of carbon, black opaque carbon of a density of from 3.0 to 3.5, and hard as diamonds—black diamonds or carbonado, in fact—and a small portion of transparent colourless diamonds showing crystalline structure. Besides these, there may be carbide of silicon and corundum, arising from impurities in the materials employed.

The residue is first heated for some hours with strong sulphuric acid at the boiling point, with the cautious addition of powdered nitre. It is then well washed, and for two days allowed to soak in strong hydrofluoric acid

<sup>1</sup> A pressure of fifteen tons on the square inch would exist not many miles beneath the surface of the earth.

<sup>2</sup> There are abundant signs that a considerable portion of this part of Africa was once under water, and a fresh-water shell has been found in apparently undisturbed blue ground at Kimberley.

<sup>3</sup> The water sunk in wells close to the Kimberley mine is sometimes impregnated with paraffin, and Sir H. Roscoe extracted a solid hydrocarbon from the "blue ground."



in cold, then in boiling acid. After this treatment the soft graphite disappears, and most, if not all, the silicon compounds have been destroyed. Hot sulphuric acid is again applied to destroy the fluorides, and the residue, well washed, is attacked with a mixture of the strongest nitric acid and powdered potassium chlorate, kept warm—but not above 60° C., to avoid explosions. This treatment must be repeated six or eight times, when all the hard graphite will gradually be dissolved, and little else left but graphitic oxide, diamond, and the harder carbonado and boart. The residue is fused for an hour in fluoride of potassium, then boiled out in water, and again heated in sulphuric acid. The well washed grains which resist this energetic treatment are dried, carefully deposited on a slide, and examined under the microscope. Along with numerous pieces of black diamond are seen transparent colourless pieces, some amorphous, others with a crystalline appearance. Although many fragments of crystals occur, it is remarkable I have never seen a complete crystal. All appear shattered, as if on being liberated from the intense pressure under which they were formed they burst asunder. I have singular evidence of this phenomenon. A fine piece of artificial diamond, carefully mounted by me on a microscopic slide, exploded during the night and covered the slide with fragments. Moissan's crystals of artificial diamond sometimes broke a few weeks after their preparation, and some of the diamonds which cracked weeks or even months after their preparation showed fissures covered with minute cubes. This bursting paroxysm is not unknown at the Kimberley mines.

On the screen I will project photographs of artificial diamonds manufactured in the manner described. So far, these specimens are all microscopic. The largest artificial diamond is less than one millimetre across.

These laboratory diamonds burn in the air before the blowpipe to carbonic acid. In lustre, crystalline form, optical properties, density, and hardness, they are identical with the natural stone.

In several cases Moissan separated ten to fifteen microscopic diamonds from a single ingot. The larger of these are about 0.75 mm. long, the octahedra being 0.2 mm.

#### Boiling and Melting Point of Carbon.

On the average, the critical point of a substance is 1.5 times its absolute boiling point. Therefore the critical point of carbon should be about 5800° Ab. But the absolute critical temperature divided by the critical pressure is for all the elements so far examined never less than 2.5, this being about the value Sir James Dewar finds for hydrogen. So that, accepting this, we get the maximum critical pressure as follows, viz. 2320 atmospheres:—

$$5800^{\circ} \text{ Ab.} / \text{CrP} = 2.5, \text{ or } \text{CrP} = 5800^{\circ} \text{ Ab.} / 2.5, \text{ or } 2320 \text{ atmospheres.}$$

Carbon and arsenic are the only two elements that have a melting point above the boiling point; and among compounds carbonic acid and fluoride of silicon are the only other bodies with similar properties. Now the melting point of arsenic is about 1.2 times its absolute boiling point. With carbonic acid and fluoride of silicon the melting points are about 1.1 times their boiling points. Applying these ratios to carbon, we find that its melting point would be about 4400°.

Therefore, assuming the following data

Boiling point ... ..	3870° Ab.
Melting point ... ..	4400°
Critical temperature ... ..	5800°
Critical pressure ... ..	2320 Ats.

the Rankine or Van der Waals formula calculated from the boiling point and critical data would be as follows:—

$$\log. P = 10.11 - 39120/T,$$

and this gives for a temperature of 4400° Ab. a pressure of 16.6 Ats. as the melting-point pressure. Similar rough estimates obtained by means of this formula suggest that above a temperature of 5800° Ab. no amount of pressure will cause carbon vapour to assume liquid form, whilst at 4400° Ab. a pressure of above 17 atmospheres would suffice to liquefy some of it. Between these extremes the curve

of vapour pressure is assumed to be logarithmic, as represented in the accompanying diagram. The constant 39120 which occurs in the logarithmic formula enables us to calculate the latent heat of evaporation. If we assume the vapour density to be normal, or the molecule in vapour as  $C_2$ , then the heat of volatilisation of 12 grms. of carbon would be 90,000 calories; or, if the vapour is a condensed molecule like  $C_6$ , then the 12 grms. would need 30,000 calories. In the latter case the evaporation of 1 gm. of carbon would require 2500 calories, whereas a substance like zinc needs only about 400 calories.

#### A New Formation of Diamond.

I have long speculated as to the possibility of obtaining artificially such pressures and temperatures as would fulfil the above conditions. In their researches on the gases from fired gunpowder and cordite, Sir Frederick Abel and Sir Andrew Noble obtained in closed steel cylinders pressures as great as 95 tons to the square inch, and temperatures as high as 4000° C. According to a paper recently communicated to the Royal Society, Sir Andrew Noble, exploding cordite in closed vessels, has obtained a pressure of 8000 atmospheres, or 50 tons per square inch, with a temperature reaching in all probability 5400° Ab.

Here, then, we have conditions favourable for the liquefaction of carbon, and were the time of explosion sufficient to allow the reactions to take place, we should certainly expect to get the liquid carbon to solidify in the crystalline state.<sup>1</sup>

By the kindness of Sir Andrew Noble, I have been enabled to work upon some of the residues obtained in closed vessels after explosions, and I have submitted them to the same treatment that the granulated iron had gone through. After weeks of patient toil I removed the amorphous carbon, the graphite, the silica,<sup>2</sup> and other constituents of the ash of cordite, and obtained a residue among which, under the microscope, crystalline particles could be distinguished. Some of these particles, from their crystalline appearance and double refraction, were silicon carbide; others were probably diamonds. The whole residue was dried and fused at a good red heat in an excess of potassium bifluoride, to which was added during fusion 5 per cent. of nitre. (Previous experiments had shown me that this mixture readily attacked and dissolved silicon carbide; unfortunately it also attacks diamond to a slight degree.) The residue, after thorough washing and then heating in fuming sulphuric acid, was washed, dried, and the largest crystalline particles picked out and mounted. All the operations of washing and acid treatment were performed in a large platinum crucible by decantation (except the preliminary attack with nitric acid and potassium chlorate, when a hard glass vessel was used); the final result was washed into a shallow watch-glass, and the selection made under the microscope.

I project on the screen a few photographs of these crystals. From the treatment they have undergone, chemists will agree with me that diamonds only could stand such an ordeal; on submitting them to skilled crystallographic authorities my opinion is confirmed. Speaking of the one before you (303), Prof. Bonney calls it "a diamond showing octahedral planes with dark boundaries due to high refracting index." After careful examination, Prof. Miers writes of the same crystal diamond:—"I think one may safely say that the position and angles of its faces, and of its cleavages, the absence of birefringence, and the high refractive index, are all compatible with the properties of the diamond crystallising in the form of an octahedron. Others of the remaining crystals, which show a similar high refractive index, appeared to me to present the same features."

<sup>1</sup> Sir James Dewar, in a Friday evening discourse at the Royal Institution, 1880, showed an experiment proving that the temperature of the interior of a carbon tube heated by an outside electric arc was higher than that of the oxy-hydrogen flame. He placed a few small crystals of diamond in the carbon tube, and, maintaining a current of hydrogen to prevent oxidation, raised the temperature of the tube in an electric furnace to that of the arc. In a few minutes the diamond was transformed into graphite. At first sight this would seem to show that diamond cannot be formed at temperatures above that of the arc. It is probable, however, for reasons given above, that at exceedingly high pressures the result would be different.

<sup>2</sup> The silica was in the form of spheres, perfectly shaped and transparent, mostly colourless, but among them several of a ruby colour. When 5 per cent. of silica was added to cordite, the residue of the closed vessel explosion contained a much larger quantity of these spheres.

It would have been more conclusive had I been able to get further evidence as to the density and hardness of the crystals; but I am still working at the subject, and hope to add these confirmatory tests. From what I have already said, I think there is no doubt that in these closed vessel explosions we have another method of producing the diamond artificially.

Sensational as is the story of the diamond industry in South Africa, quite another aspect fixes the attention of the chemist. The diamonds come out of the mines, but how did they get in? How were they formed? What is their origin?

Gardner Williams, who knows more about diamonds than any man living, is little inclined to indulge in speculation. In his fascinating book<sup>1</sup> he frankly says:—

"I have been frequently asked, 'What is your theory of the original crystallisation of the diamond?' and the answer has always been, 'I have none; for after seventeen years of thoughtful study, coupled with practical research, I find that it is easier to "drive a coach and four" through most theories that have been propounded than to suggest one which would be based on any non-assailable data.' All that can be said is that in some unknown manner carbon, which existed deep down in the internal regions of the earth, was changed from its black and uninviting appearance to the most beautiful gem which ever saw the light of day."

#### *Meteoric Diamonds.*

Another diamond theory appeals to the fancy. It is said the diamond is a gift from Heaven, conveyed to earth in meteoric showers. The suggestion, I believe, was first broached by A. Meydenbauer,<sup>2</sup> who says:—"The diamond can only be of cosmic origin, having fallen as a meteorite at later periods of the earth's formation. The available localities of the diamond contain the residues of not very compact meteoric masses which may, perhaps, have fallen in prehistoric ages, and which have penetrated more or less deeply, according to the more or less resistant character of the surface where they fell. Their remains are crumbling away on exposure to the air and sun, and the rain has long ago washed away all prominent masses. The enclosed diamonds have remained scattered in the river beds, while the fine light matrix has been swept away."

According to this hypothesis, the so-called volcanic pipes are simply holes bored in the solid earth by the impact of monstrous meteors—the larger masses boring the holes, while the smaller masses, disintegrating in their fall, distributed diamonds broadcast. Bizarre as such a theory appears, I am bound to say there are many circumstances which show that the notion of the heavens raining diamonds is not impossible.

The most striking confirmation of the meteoric theory comes from Arizona. Here, on a broad open plain, over an area about five miles in diameter, have been scattered one or two thousand masses of metallic iron, the fragments varying in weight from half a ton to a fraction of an ounce. There is little doubt these masses formed part of a meteoric shower, although no record exists as to when the fall took place. Curiously enough, near the centre, where most of the meteorites have been found, is a crater with raised edges three-quarters of a mile in diameter and about 600 feet deep, bearing exactly the appearance which would be produced had a mighty mass of iron struck the ground and buried itself deep under the surface. Altogether ten tons of this iron have been collected, and specimens of the Canyon Diablo meteorite are in most collectors' cabinets.

An ardent mineralogist—the late Dr. Foote—cutting a section of this meteorite, found the tools were injured by something vastly harder than metallic iron. He examined the specimen chemically, and soon after announced to the scientific world that the Canyon Diablo meteorite contained black and transparent diamonds. This startling discovery was afterwards verified by Profs. Moissan and Friedel, and Moissan, working on 183 kilograms of the Canyon Diablo meteorite, has recently found smooth black diamonds and transparent diamonds in the form of octahedra with rounded edges, together with green hexagonal

crystals of carbon silicide. The presence of carbon silicide in the meteorite shows that it must, at some time, have experienced the temperature of the electric furnace. Since this revelation, the search for diamonds in meteorites has occupied the attention of chemists all over the world.

I am enabled to show you photographs of true diamonds I myself have extracted from the Canyon Diablo meteorite. A fine slab of the meteorite, weighing about seven pounds, is on the table before you.

Here, then, we have incontestable proof of the truth of the meteoric theory. Under atmospheric influences the iron would rapidly oxidise and rust away, colouring the adjacent soil with red oxide of iron. The meteoric diamonds would be unaffected, and left on the surface of the soil, to be found haphazard when oxidation had removed the last proof of their celestial origin. That there are still lumps of iron left at Arizona is merely due to the extreme dryness of the climate and the comparatively short time that the iron has been on our planet. We are here witnesses to the course of an event which may have happened in geologic times anywhere on the earth's surface.

Although in Arizona diamonds have fallen from the skies, confounding our senses, this descent of precious stones is what may be called a freak of nature rather than a normal occurrence. To the modern student of science there is no great difference between the composition of our earth and that of extra-terrestrial masses. The mineral peridot is a constant extra-terrestrial visitor, present in most meteorites; and yet no one doubts that peridot is also a true constituent of rocks formed on this earth. The spectroscope reveals that the elementary composition of the stars and the earth is pretty much the same; and the spectroscope also shows that meteorites have as much of earth as of heaven in their composition. Indeed, not only are the self-same elements present in meteorites, but they are combined in the same way to form the same minerals as in the crust of the earth.

It is certain from observations I have made, corroborated by experience gained in the laboratory, that iron at a high temperature and under great pressure—conditions existent at great depths below the surface of the earth—acts as the long-sought solvent for carbon, and will allow it to crystallise out in the form of diamond. But it is also certain, from the evidence afforded by the Arizona and other meteorites, that similar conditions have existed among bodies in space, and that on more than one occasion a meteorite freighted with jewels has fallen as a star from the sky.

Many circumstances point to the conclusion that the diamond of the chemist and the diamond of the mine are strangely akin as to origin. It is evident that the diamond has not been formed *in situ* in the blue ground. The genesis must have taken place at vast depths under enormous pressure. The explosion of large diamonds on coming to the surface shows extreme tension. More diamonds are found in fragments and splinters than in perfect crystals; and it is noteworthy that although these splinters and fragments must be derived from the breaking up of a large crystal, yet in only one instance have pieces been found which could be fitted together, and these occurred at different levels. Does not this fact point to the conclusion that the blue ground is not their true matrix? Nature does not make fragments of crystals. As the edges of the crystals are still sharp and unabraded, the *locus* of formation cannot have been very distant from the present sites. There were probably many sites of crystallisation differing in place and time, or we should not see such distinctive characters in the gems from different mines, nor, indeed, in the diamonds from different parts of the same mine.

It is not difficult to imagine that masses of iron saturated with carbon existed formerly at a sufficient depth below the present mines, where temperature and pressure would produce the reactions which laboratory experiments show to be probable.

Many crystals of diamonds have their surfaces beautifully marked with equilateral triangles, interlaced and of varying sizes. Under the microscope these markings appear as shallow depressions sharply cut out of the surrounding surface; these depressions were supposed by Gustav Rose to indicate the probability that the diamonds at some

<sup>1</sup> "The Diamond Mines of South Africa," p. 510. (Macmillans, 1902.)

<sup>2</sup> *Chemical News*, vol. lxi., p. 209, 1890.



previous time had been exposed to incipient combustion. Rose also noted that striations appeared on the surfaces of diamonds burnt before the blowpipe.

I have tried many times to imitate these markings by partial combustion of clear crystals of diamond, but have not succeeded in reproducing triangles of such beauty as you see formed by nature. According to the crystalline face exposed to incipient combustion the etchings are triangular or cubical, and sometimes intermediate between the two. I throw on the screen magnified photographs of these etchings, and you will observe that while the triangular or box-like tendency is very apparent, there is an absence of regularity and sharpness.

The artificial markings are closer massed, looking as if the diamond during combustion had been dissected into triangular and rectangular flakes, while the markings natural to crystals appear as if produced by the crystallising force as they were being built up.

Certain artificial diamonds present the appearance of an elongated drop. I have seen diamonds which have exactly the appearance of drops of liquid separated in a pasty condition and crystallised on cooling. Diamonds are sometimes found with little appearance of crystallisation, but with rounded forms similar to those which a liquid might assume if kept in the midst of another liquid with which it would not mix. Other drops of liquid carbon retained for sufficient time above their melting point would coalesce with adjacent drops, and on slow cooling would separate in the form of large perfect crystals. Two drops, joining after incipient crystallisation, might assume the not uncommon form of interpenetrating twin crystals. Illustrations of all these caprices are here to-night.

Again, diamond crystals are generally perfect on all sides. They show no irregular side or face by which they were attached to a support, as do artificial crystals of chemical salts; another proof that the diamond must have crystallised from a dense liquid.

Having no double refraction, the diamond should not act on polarised light. But, as is well known, if a transparent body which does not so act is submitted to strain of an irregular character it becomes doubly refracting, and in the polariscope reveals the existence of the strain by brilliant colours arranged in a more or less defined pattern according to the state of tension in which the crystal exists. I have examined many hundred diamond crystals under polarised light, and with few exceptions all show the presence of internal tension. I will project some diamonds on the screen by means of the polarising microscope, and you will see by the colours how great is the strain to which some of them are exposed. On rotating the polariser, the black cross most frequently seen revolves round a particular point in the inside of the crystal; on examining this point with a high power, we sometimes see a slight flaw, more rarely a minute cavity. The cavity is filled with gas at enormous pressure, and the strain is set up in the stone by the effort of the gas to escape. I have already told you that the great Cullinan diamond by this means reveals a state of internal stress and strain.

It is not uncommon for a diamond to explode soon after it reaches the surface; some have been known to burst in the pockets of the miners or when held in the warm hand, and the loss is the greater because large stones are more liable to explode or fly in pieces than small ones. Valuable stones have been destroyed in this way, and it is whispered that cunning dealers are not averse to allowing responsible clients to handle or carry in their warm pockets large crystals fresh from the mine. By way of safeguard against explosion, some dealers imbed large diamonds in raw potato to ensure safe transit to England.

The anomalous action which many diamonds exert on polarised light is not such as can be induced by heat, but it can easily be conferred on diamonds by pressure, showing that the strain has not been produced by sudden cooling, but by sudden lowering of pressure.

The illustration of this peculiarity is not only difficult, but sometimes exceedingly costly—difficult because it is necessary to arrange for projecting on the screen the image of a diamond crystal between the jaws of a hydraulic press, the illuminating light having to pass through delicate optical polarising apparatus—and costly because only perfect, clear crystals can be used, and crystals of this

character sometimes fly to pieces as the pressure rises. No colour as yet is seen on the screen, the crystal not being birefringent. A movement of the handle of the press, however, gives the crystal a pinch, instantly responded to by the colours on the screen, showing the production of double refraction. Another movement of the handle brightens the colours; a third may strain the crystal beyond its power of resistance, so I refrain.

#### Hardness.

Diamonds vary considerably in hardness, and even different parts of the same crystal differ in their resistance to cutting and grinding.

Beautifully white diamonds have been found at Inverel, New South Wales, and from the rich yield of the mine and the white colour of the stones, great things were expected. In the first parcel which came to England the stones were found to be so much harder than South African diamonds that it was at first feared they would be useless except for rock-boring purposes. The difficulty of cutting them disappeared with improved appliances, and they now are highly prized.

The famous Koh-i-noor, when cut into its present form, showed a notable variation in hardness. In cutting one of the facets near a yellow flaw, the crystal became harder and harder the further it was cut, and after working the mill for six hours at the usual speed of 2400 revolutions a minute, little impression was made. The speed was increased to more than 3000, when the work slowly proceeded. Other portions of the stone were found to be comparatively soft, and hardened as the outside was cut away.

I can illustrate the intense hardness of the diamond by experiment. On the flattened apex of a conical block of steel I place a diamond, and upon it I bring down a second cone of steel. With the lamp I project an image of the diamond and steel faces on the screen, and force them together by hydraulic power. I can squeeze the stone into the steel blocks without injuring it in the slightest degree.

The pressure gauge shows 60 atmospheres, and the piston being 3.2 inches diameter, the absolute pressure is 3.16 tons, equivalent on a diamond of 12 square mm. surface to 170 tons per square inch of diamond.

Although not directly bearing on the subject, I will introduce the only serious rival of the diamond as regards hardness. It is the metal tantalum, a fine specimen of which I owe to Messrs. Siemens Brothers. A hole had to be bored through a plate of this metal, and a diamond drill was used revolving at the rate of 5000 revolutions per minute. This whirling force was continued ceaselessly for three days and nights, when it was found that only a small depression  $\frac{1}{4}$  mm. deep had been drilled, and it was a moot point which had suffered most damage, the diamond or the tantalum.<sup>1</sup> In another respect tantalum is likely to rival graphitic carbon, as it has rivalled adamantite carbon. Its thin wire is extensively used for filaments of incandescent electric lamps; it shows a much higher efficiency than does the old carbon filament. The melting point of tantalum is about 2300° C., a temperature seldom or never reached in an ordinary lamp.

#### Refractivity.

But it is not the hardness of the diamond so much as its optical qualities that make it so highly prized. It is one of the most refracting substances in nature, and it also has the highest reflecting properties. In the cutting of diamonds advantage is taken of these qualities. When cut as a brilliant the facets on the lower side are inclined so that light falls on them at an angle of 24° 13', at which angle all the incident light is totally reflected. A well cut brilliant should appear opaque by transmitted light except at a small spot in the middle where the table and culet are opposite. All the light falling on the front of the stone is reflected from the facets, and the light passing into the diamond is reflected from the interior surfaces and refracted into colours when it passes out into the air, giving rise to the lightnings, the effulgence, and coruscations for which the diamond is supreme above all other gems.

In vain I have searched for a liquid of the same refrac-

<sup>1</sup> W. von Bolton *Zeitschr. Elektrochem.*, ii., 45-51, January 20, 1905

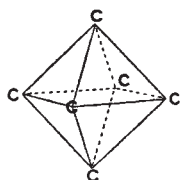
tion as diamond. Such a liquid would be invaluable to the merchant, as on immersing a stone the clear body would absolutely disappear, leaving in all their ugliness the flaws and black specks so frequently seen even in the best stones.

Arguing from theoretical considerations connected with the specific refractive energy of diamond, and employing Lorentz's expression for refraction—

$$\left(\frac{\mu^2 - 1}{\mu^2 + 2} \frac{P}{d}\right),$$

in which  $\mu$ =refractive index,  $\mu-1$ =refractive energy,  $d$ =density, and  $P$ =molecular weight, Brühl has shown that diamond is perfectly normal in its optical properties, and has an atomic refraction =5. He has put forward the speculation that the diamond may be the last member of the paraffin series of which marsh-gas is the first.

"Now we can imagine," says Brühl,<sup>1</sup> "why the diamond, *i.e.* pure crystallised carbon, is optically normal. We obtain an idea of the mineral's chemical constitution, and of the way in which the atoms of carbon are perhaps combined in the sparkling gem. The diamond cannot possibly contain any double bonds. Imagine, however, at each of the six corners of a regular octahedron, a single molecule of marsh-gas,  $\text{CH}_4$ , *i.e.* altogether  $\text{C}_6\text{H}_{24}$ , and then imagine all the 24 hydrogen atoms successively removed, so that each carbon atom is connected with each of its neighbours only by a single bond, and thus all six atoms of carbon are united together in a single whole. Then you obtain, as the most simple representation of the molecule of the diamond, a regular octahedron, with one atom of carbon at each of its six corners, whilst the edges represent the mutual bonds:—



Several simple molecules of this kind may be combined into one crystallised particle of the spectrochemically normal diamond."

#### Absorption Spectrum of Diamond.

On passing a ray of light through a diamond and examining it in a spectroscope, B. Walter has found in all colourless brilliants of more than one carat in weight an absorption band at wave-length 4155 (violet). He ascribes this band to an impurity, and suggests it may possibly be due to samarium. Three other fainter lines were detected in the ultra-violet by means of photography.

#### Phosphorescence of Diamond.

After exposure for some time to the sun many diamonds glow in a dark room. Some diamonds are fluorescent, appearing milky in sunlight. In a vacuum, exposed to a high-tension current of electricity, diamonds phosphoresce of different colours, most South African diamonds shining with a bluish light. Diamonds from other localities emit bright blue, apricot, pale blue, red, yellowish green, orange, and pale green light. The most phosphorescent diamonds are those which are fluorescent in the sun. One beautiful green diamond in my collection, when phosphorescing in a good vacuum, gives almost as much light as a candle, and you can easily read by its rays. But the time has hardly come when diamonds can be used as domestic illuminants! The emitted light is pale green, tending to white, and in its spectrum, when strong, can be seen bright lines, one at about  $\lambda$  5370 in the green, one at  $\lambda$  5130 in the greenish blue, and one at  $\lambda$  5030 in the blue.

After many years' bombardment in a vacuum tube this diamond grew very dark, almost black, on the surface. Heating in a mixture of nitric acid and potassium chlorate scarcely changed the colour. The action of heat was then tried, and on slowly heating to about 500° C. the dark

colour entirely disappeared, and the original milky green appearance was restored. Although I watched narrowly I could see no trace of phosphorescence during the heating.

Diamonds which phosphoresce red generally show the yellow sodium line superposing on a continuous spectrum. In one Brazilian diamond phosphorescing a reddish yellow colour, I detected the citron line characteristic of yttrium.

By permission of Mrs. Kunz, wife of the well known New York mineralogist, I will show you perhaps the most remarkable of all phosphorescing diamonds. This prodigy diamond will phosphoresce in the dark for some minutes after being exposed to a small pocket electric light, and if rubbed on a piece of cloth a long streak of phosphorescence appears.

#### Tribo-luminescence.

A few minerals give out light when rubbed, and Mrs. Kunz's diamond is equally striking in this respect. In the year 1663, the Hon. Robert Boyle read a paper before the Royal Society, in which he described several experiments made with a diamond which markedly showed tribo-luminescence. As specimens of tribo-luminescent bodies, I show you sphalerite (sulphide of zinc) and an artificial sphalerite, which is even more responsive to friction than the native sulphide.<sup>1</sup>

#### Combustion of the Diamond.

When heated in air or oxygen to a temperature varying from 760° C. to 875° C., according to its hardness, the diamond burns with production of carbonic acid. It leaves an extremely light ash, sometimes retaining the shape of the crystal, consisting of iron, lime, magnesia, silica, and titanium. In boart and carbonado the amount of ash sometimes rises to 4 per cent., but in clear crystallised diamonds it is seldom higher than 0.05 per cent. By far the largest constituent of the ash is iron.

#### Action of Radium on Diamond.

The  $\beta$  rays from radium having like properties to the stream of negative electrons in a radiant matter tube, it was of interest to ascertain if they would exert a like difference on diamond. The diamond glows under the influence of the  $\beta$  radiations, and crushed diamond cemented to a piece of card or metal makes an excellent screen in a spinthariscopes—almost as good as zinc sulphide. Some fine colourless crystals of diamond were embedded in radium bromide and kept undisturbed for more than twelve months. At the end of that time they were examined. The radium had caused them to assume a beautiful blue colour, and their value as "fancy stones" had been materially increased. Here are a couple of diamonds originally of the same purity of water. One has been coloured by radium, the other is in its natural state. The colour of the radium-tinted stone is very pronounced. The lantern slide shows the darkening thus produced. A and B are diamonds after twelve months' burial in radium bromide; diamond C is of the original colour.

This blue colour is persistent, and penetrates below the surface. It is unaffected by long-continued heating in strong nitric acid and potassium chlorate, and is not discharged by heating to redness.

To find out if this prolonged contact with radium had communicated to the diamond any radio-active properties, six diamonds were put on a photographic plate, and kept in the dark for a few hours. I will project the image of the result after development. The three on the upper row are the diamonds which have had a prolonged sojourn with radium, the three below are similar diamonds picked out for comparison, which have not been near radium. See how strangely the three upper ones have acted. Notice also that by mere contiguity to the others the lower diamonds also shine with an induced, factitious radio-activity. I throw on the screen a magnified image of one of the blue crystals, and you see in how regular and geometrical a pattern the radio-active emanations radiate from the crystal. This observation has only been made

#### Artificial tribo-luminescent sphalerite:—

Zinc carbonate	...	...	...	100 parts
Flower of sulphur	...	...	...	30 "
Manganese sulphate	...	...	...	1/2 per cent.

Mix with distilled water and dry at a gentle heat. Put in luted crucible and keep at a bright red heat for from two to three hours.

<sup>1</sup> *Proceedings of the Royal Institution*, May 26, 1905.



a short time, and is still under investigation. Like the blue tint, the radio-activity persists after drastic treatment. To me this proves that radio-activity does not merely consist in the adhesion of electrons or emanations given off by radium, to the surface of an adjacent body, but the property is one involving layers below the surface, and like the alteration of tint is probably closely connected with the intense molecular excitement the stone had experienced during its twelve months' burial in radium bromide.

A diamond that had been coloured blue by radium, and had acquired strong radio-active properties, was slowly heated to dull redness in a dark room. Just before visibility a faint phosphorescence spread over the stone. On cooling and examining the diamond, it was found that neither the colour nor the radio-activity had suffered appreciably.

The diamond is remarkable in another respect. It is extremely transparent to the Röntgen rays, whereas highly refracting glass, used in imitation diamonds, is almost perfectly opaque to the rays. I exposed for a few seconds over a photographic plate to the X-rays the large Delhi diamond of a rose-pink colour weighing  $31\frac{1}{4}$  carats, a black diamond weighing 23 carats, and a glass imitation of the pink diamond. On development, the impression where the diamond obscured the rays was found to be strong, showing that most rays passed through, while the glass was practically opaque. By this means imitation diamonds can readily be distinguished from true gems.

I have already signified that there are various degrees of refractoriness to chemical reagents among the different forms of graphite. Some dissolve in strong nitric acid; other forms of graphite require a mixture of highly concentrated nitric acid and potassium chlorate to attack them, and even with this intensely powerful agent some graphites resist longer than others. M. Moissan has shown that the power of resistance to nitric acid and potassium chlorate is in proportion to the temperature at which the graphite was formed, and with tolerable certainty we can estimate this temperature by the resistance of the specimen of graphite to this reagent.

The superficial dark coating on a diamond after exposure to molecular bombardment I have proved to be graphite.<sup>1</sup> M. Moissan<sup>2</sup> has shown that this graphite, on account of its great resistance to oxidising reagents, cannot have been formed at a lower temperature than  $3600^{\circ}\text{C}$ .

It is thus manifest that the bombarding electrons endowed with an electric charge, and striking the diamond with enormous velocity, raise the superficial layer to the temperature of the electric arc, and turn it into graphite, whilst the mass of diamond and its conductivity to heat are sufficient to keep down the general temperature to such a point that the tube appears scarcely more than warm to the touch.

A similar action occurs with silver, the superficial layers of which can be raised to a red heat without the whole mass becoming more than warm.<sup>3</sup>

I will now direct your attention to a strange property of the diamond, which at first sight might seem to discount the great permanence and unalterability of this stone. It has been ascertained that the cause of phosphorescence is in some way connected with the hammering of the electrons, violently driven from the negative pole, on to the surface of the body under examination, and so great is the energy of the bombardment that impinging on a piece of platinum or even iridium the metal will actually melt. When the diamond is thus bombarded in a radiant matter tube the result is startling. It not only phosphoresces, but assumes a brown colour, and when the action is long-continued becomes almost black.

I will project a diamond on the screen and bombard it with radiant matter before your eyes. I do not like to anticipate a failure, but I am at the mercy of my diamond. I cannot rehearse this experiment, and it may happen that the diamond I have selected will show caprice and not blacken in reasonable time. Some diamonds visibly darken in a few minutes, while others, more leisurely in their ways, require an hour.

This blackening is only superficial, but no ordinary means of cleaning will remove the discoloration. Ordinary

oxidising reagents have little or no effect in restoring the colour. The black stain on the diamond is due to a form of graphite which is resistant to oxidation.

#### *Conversion of Diamond into Graphite.*

Although we cannot convert graphite into diamond, we can change the diamond into graphite. I take a clear crystal of diamond and place it between two carbon poles, and throw the image on the screen by means of a powerful arc lamp behind. I now bring the poles with intervening diamond together and form an arc between. The temperature of the diamond rapidly rises, and when it approaches  $3600^{\circ}\text{C}$ ., the vaporising point of carbon, it breaks down, swells, and changes into black and valueless graphite. I show this experiment because it is striking and suggestive. I may add that it is costly—because the stone, if not of fine quality, might easily burst.

### UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

SIR CLEMENTS R. MARKHAM, K.C.B., F.R.S., will deliver an address at Cambridge on Thursday, October 19, introductory to the courses of instruction in geography.

Science announces the death of General Isaac J. Wistar, of Philadelphia, founder of the Wistar Institute of Anatomy and Biology of the University of Pennsylvania, formerly president of the American Philosophical Society. By his will the Wistar Institute will receive the residue of his estate, thought to amount to about 80,000.

IN the course of an address to the students of Cornell University in 1903, President Schurman emphasised the necessity of a systematic distribution of the daily time of college students. He recommended the following general apportionment of hours:—for work, eleven; for sleep, eight; for amusement, one; for meals and athletics, two hours each. Work is made to include not only time spent in the laboratory and lecture-room and in private study, but also time given to societies and to self-support. This advice led Dr. Guy M. Whipple, of Cornell University, to try to ascertain how the students in his university actually do distribute their daily time. The results of his inquiries are described in an article in the current number of the *Popular Science Monthly*. In the summary to the detailed tables given in his article Dr. Whipple states that, taking the university as a whole, the average Cornell student devotes just nine hours daily to college work, sleeps 7.9 hours, devotes 2.23 hours to amusement, 1.72 hours to physical exercise, 1.4 hours to meals, 0.39 hour to self-support, and 1.36 hours to unclassified activities. The average length of time given to work is greatest in the college of medicine, and progressively less in those of engineering, law, agriculture, and arts. Both in the university at large and within the College of Arts and Sciences, men give more time to college work than women.

PROF. J. W. JUDD, F.R.S., distributed on October 5 the medals and prizes gained during the past session by the students of the Royal College of Science, London, in the lecture theatre of the Victoria and Albert Museum, South Kensington. The Dean, Prof. Tilden, F.R.S., in opening the proceedings, referred with regret to several losses which the college and school had sustained during the year, alluding particularly to the death of Prof. Howes. The geological division had lost its chief by the retirement of Prof. Judd. The college is now, the Dean continued, in an attitude of expectancy in regard to the future, and it is possible that next year they will be able to hold the prize distribution in the new buildings. He said that in ten years seventy-six of the students of the college have taken the degree of B.Sc., and, in addition, thirty have taken first-class honours, besides which there are nine doctors of science. Prof. Judd, having distributed the awards, addressed the students. He acknowledged the uniform courtesy and consideration which he had received from colleagues and students alike during his forty-five years' experience in connection with the school. Nearly two-thirds of that period had been spent in the position of one of the teachers. He congratulated them on the expansion and development which is now promised, and expressed the hope that the change would lead to even

<sup>1</sup> *Chemical News*, vol. lxxiv., p. 39, July, 1896.

<sup>2</sup> *Comptes rendus*, cxxiv., p. 653.

<sup>3</sup> *Proc. Roy. Soc.*, vol. l., p. 99, June, 1891.